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FOR A

DIRECT-CONVERSION TRANSMITTER

SYSTEM AND METHOD WITH

QUADRATURE BALANCING AND LOW

LO FEED THROUGH

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DIRECT CONVERSION TRANSMITTER SYSTEM AND METHOD WITH QUADRATURE BALANCING AND LOW LO FEED THROUGH

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RELATED APPLICATION(S)

The present application claims priority from a provisional patent application filed
03/24/03 under App. Serial No.: 60/456,510, which is incorporated herein by reference.

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FIELD OF THE INVENTION

The present invention relates to circuitry, and more particularly to direct-conversion
circuitry.

15

BACKGROUND OF THE INVENTION

Direct-conversion is an alternative wireless transmitter architecture to the well-
established superheterodyne, particularly for highly integrated, low-power terminals.

20 Its fundamental advantage is that the transmitted signal is mixed directly to radio
frequency (RF) without the use of an intermediate frequency. This means less
hardware complexity, lower component count and a simpler frequency plan.

In direct-conversion transmitters the most serious problem is that of local oscillator
25 (“LO”) feed-through due to a variety of on-chip coupling mechanisms. While the
LO is necessary to convert the baseband signal to RF for transmission, if significant
LO leakage occurs in the middle of the up-converted signal spectrum, the signal will
be corrupted and rendered unreceivable.

Furthermore, in modern communication systems, the transmitter must be able to control the power that it is transmitting. The LO feed-through amplitude cannot be controlled as it is an unwanted byproduct of circuit non-idealities. This forces the transmitting signal to always be much larger than the LO feed-through.

- 5 Traditionally, LO feed-through can be reduced through the use of on-chip or external calibration schemes at the cost of additional hardware size and complexity.

Another problem in direct-conversion transmitters is in-phase and quadrature (“IQ”) imbalance of the LO and signal path. Traditionally, direct conversion transmitters
10 and receivers need a local oscillator with quadrature outputs for vector modulation and demodulation. However, when the quadrature signal components are not equal in amplitude and not exactly 90 degrees out of phase, the signal degrades in quality.

Quadrature phases are typically derived by passing a reference local oscillator
15 through a CR-RC phase shift network. Ideally, this creates two signals with equal amplitude and 90 degrees of phase difference. However, this depends on the accuracy of resistors and capacitors which make up the phase shift network. The resistors and capacitors can vary by up to 15 percent in a typical integrated circuit causing the in-phase and quadrature components to have different amplitudes and a
20 phase difference not equal to 90 degrees.

In addition, layout differences between the in-phase and quadrature paths can cause additional amplitude/phase imbalance. Contributing to further in-phase/quadrature imbalance, the circuits in the in-phase and quadrature paths (i.e. amplifiers and
25 mixers) have physical properties that differ. Many feedback calibration schemes have been proposed and implemented to mitigate quadrature imbalance at the cost of hardware and/or system complexity.

A conventional direct conversion transmitter is illustrated in FIG. 1. As illustrated
30 in FIG. 1, a direct conversion transmitter takes the modulated in-phase and quadrature baseband signals 100, 101 and translates the signal to an RF frequency by

multiplying them by a quadrature LO. Specifically, the transmitter multiplies the baseband signals **100**, **101** with two different phases **102**, **103** of a local oscillator **107** using a first mixer **110** and a second mixer **111**. The in-phase and quadrature baseband signals can be denoted BB_I and BB_Q . The two phases **102**, **103** of the local oscillator are 90 degrees apart and thus, are known as the in-phase (“I”) **102** and quadrature (“Q”) **103** components and can be denoted LO_I and LO_Q respectively. The mixer outputs **104**, **105** are summed together to produce the RF signal **106**. The RF signal **106** can be represented by Equation 1.

$$RF = BB_I \times LO_I + BB_Q \times LO_Q \quad \text{Equation 1}$$

Another conventional direct conversion architecture is shown in FIG. 2. This differential direct conversion architecture is more resilient to self generated noise than the one illustrated in FIG. 1. In FIG. 2, the I and Q baseband signals are differential signals composed of positive and negative components. The equivalent single-ended baseband in-phase signal to the differential baseband in-phase signal is described by Equation 2. In Equation 2, BB_I denotes the single-ended in-phase signal, $BB_{I,pos}$ denotes the positive component of the differential signal, and $BB_{I,neg}$ denotes the negative component of the differential signal. A differential signal has a positive and negative component which subtract to form the signal. Equation 3 describes the quadrature relationship in similar terms.

$$BB_I = (BB_{I,pos} - BB_{I,neg}) \quad \text{Equation 2}$$

$$BB_Q = (BB_{Q,pos} - BB_{Q,neg}) \quad \text{Equation 3}$$

In Equation 2 and Equation 3, $BB_{I,pos}$, $BB_{I,neg}$, $BB_{Q,pos}$, $BB_{Q,neg}$ correspond to **200**, **201**, **202**, **203**, respectively, in FIG. 2.

The differential direct conversion architecture shown in FIG. 2 uses differential LO signals to mix the baseband signal to RF. The polyphase network **205** is a circuit

which converts the local oscillator voltage waveform **204** into four voltage waveforms **206, 207, 208, 209** at the same frequency as LO but at 0, 180, 90, 270 degrees offset compared to the local oscillator signal **204** respectively.

- 5 Collectively, these four signals **206, 207, 208, 209** are referred to as polyphase local oscillator signals. To facilitate the present description, the following signals **206, 207, 208, 209** are denoted as LO^0 , LO^{180} , LO^{90} , LO^{270} corresponding to their phase shift compared to the local oscillator **204**. Shifting a sinusoidal signal 180 degrees in phase is the same as inverting the signal. Therefore, the equivalent single-ended
- 10 in-phase and quadrature LO signals, denoted LO_I and LO_Q , are described mathematically in Equations 4 and 5.

$$LO_I = LO^0 - LO^{180} \quad \text{Equation 4}$$

$$LO_Q = LO^{90} - LO^{270} \quad \text{Equation 5}$$

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The differential quadrature baseband signals are routed to the differential mixers **210, 211** where they are multiplied by the differential local oscillator signals.

- At the first mixer **210**, the differential in-phase baseband signal (BB_I) is multiplied
- 20 by the in-phase LO (LO_I). Likewise, at the second mixer **211**, the differential quadrature baseband signal (BB_Q) is multiplied by the quadrature LO (LO_Q). Equation 6 describes the mixing process and summing process **212** of the differential signals to generate the RF signal **213**. Likewise, Equation 7 is a simplified version of Equation 6 where all the differential signals are represented as single-ended
- 25 signals.

$$RF = (BB_{I,pos} - BB_{I,neg}) \times (LO^0 - LO^{180}) + (BB_{Q,pos} - BB_{Q,neg}) \times (LO^{90} - LO^{270}) \quad \text{Equation 6}$$

30 $RF = BB_I \times LO_I + BB_Q \times LO_Q \quad \text{Equation 7}$

Now, to elucidate the problems with direct conversion transmitters, LO feed-through and imbalance distortions will be added to Equations 6 and 7. LO feed-through is added to the output of the mixers. LO_{C1} represents the differential LO feed-through from the polyphase LO signal to the output of mixer **210**, and LO_{C2} represents the differential LO feed-through at the at output of mixer **211**. Likewise the amplitude and phase imbalance of the mixers and the polyphase LO signals can be accounted for at the output of each mixer. A complex multiplicative term, $A1e^{jP1}$, represents a random amplitude variation (“A1”) and a random phase variation (“P1”) introduced by the first mixer **210**, the signal path **200, 201** and LO path **206, 207** connected to the mixer. Likewise, $A2e^{jP2}$ represents a random amplitude and phase variation introduced by the second mixer **211** and the signal **202, 203** and LO paths **208, 209** connected to it. Thus, with these distortions added, Equations 6 and 7 become Equations 8 and 9.

$$RF = (BB_{I,pos} - BB_{I,neg}) X (LO^0 - LO^{180}) X A1e^{jP1} + LO_{C1} + (BB_{Q,pos} - BB_{Q,neg}) X (LO^{90} - LO^{270}) X A2e^{jP2} + LO_{C2}$$

Equation 8

$$RF = BB_I X LO_I X A1e^{jP1} + LO_{C1} + BB_Q X LO_Q X A2e^{jP2} + LO_{C2}$$

Equation 9

As seen in Equations 8 and 9, the RF distortion grows as A1 and A2 differ and as P1 and P2 differ. As the distortion increase, it is harder for the signal to be received and decoded. Likewise as LO_{C1} and LO_{C2} increase, they become the dominant component of the RF signal in Equation 8 and 9.

There is thus a need for a transmitter for overcoming these problems and/or providing general improvements over prior art transmitters.

SUMMARY OF THE INVENTION

A system and method are provided for communicating a radio frequency (RF) signal.

5 In use, a baseband signal is mixed with a plurality of oscillator signals with different phases in an interleaving manner. The mixed baseband signal is then communicated as an RF signal.

In one embodiment, the oscillator signals may include an oscillator signal frequency
10 substantially equal to an RF signal frequency of the RF signal. Further, the RF signal may be modulated over a finite bandwidth.

In another embodiment, the oscillator signals may have phase differences of 0, 90, 180, and 270 degrees. Further, the mixing may be carried out by a plurality of
15 mixers.

In use, the oscillator signals may be input to the mixers in the interleaving manner. Moreover, this may be accomplished by switching which oscillator signals are input to which mixers. Still yet, the switching may occur at a rate that is faster than a
20 bandwidth of the RF signal. Optionally, the switching may occur in a substantially random manner, or even in a random manner.

In still another embodiment, the baseband signal may be inverted using an interleaving operation. Also, the baseband signal may be routed to at least one mixer
25 using an interleaving operation. A plurality of the baseband signals may be provided including an in-phase baseband signal and a quadrature baseband signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a conventional single-ended direct-conversion
5 transmitter;

FIG. 2 is a block diagram of the conventional differential direct-conversion
transmitter;

10 FIG. 3 is a block diagram of a differential direct-conversion transmitter with local-
oscillator phase interleaving and baseband signal interleaving;

FIGs. 4a-d show the four configurations of the baseband signal interleaver;

15 FIGs. 5a-d show the four configurations of the local-oscillator phase interleaver;

FIG. 6 is an illustration of a wireless communication system in which one
embodiment may be used; and

20 FIG. 7 illustrates the functional components of a wireless communication device,
shown in block diagram format.

25

DETAILED DESCRIPTION

Turning to one embodiment in FIG. 3, the differential direct conversion architecture described in FIG. 2 is enhanced with two switching matrices: 1) the local oscillator phase interleaver (“LOPI”) 326 circuit, and 2) the baseband interleaver (“BBI”) 304. Each has four combinations of connections.

The BBI 304 routes the in-phase baseband signals 300, 301 and quadrature baseband signals 302, 303 to a first up-conversion mixer 309 and the second up-conversion mixer 310. Continuing the terminology established in the example of FIG. 2, the differential in-phase baseband signals are denoted $BB_{I,pos}$, $BB_{I,neg}$ while the differential quadrature signals are denoted $BB_{Q,pos}$, $BB_{Q,neg}$. By periodically switching the BBI configuration, the in-phase and quadrature baseband signals are routed alternately to each mixer. Thus, any imbalances in the baseband path affect the in-phase and quadrature signals similarly mitigating the adverse effect.

The baseband interleaver 304 circuit switches between one of four combinations of connections illustrated in FIG. 4. In addition, in two of the states it inverts the incoming baseband signals. In state 1 illustrated in FIG. 4a, the baseband interleaver passes $BB_{I,pos}$ 400 and $BB_{I,neg}$ 401 to the first mixer and $BB_{Q,pos}$ 402 and $BB_{Q,neg}$ 403 to the second mixer.

In the second state illustrated in FIG 4b, the baseband interleaver inverts the incoming signals, $BB_{I,pos}$ 410 and $BB_{I,neg}$ 411, prior to routing them to the first mixer. Likewise, the baseband interleaver inverts $BB_{Q,pos}$ 412 and $BB_{Q,neg}$ 413 before routing them to the second mixer. In state 3 illustrated in FIG. 4c, $BB_{I,pos}$ 420 and $BB_{I,neg}$ 421 are routed to the second mixer while $BB_{Q,pos}$ 422 and $BB_{Q,neg}$ 403 are routed to the first mixer.

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Finally in state 4 illustrated in FIG. 4d, the baseband interleaver inverts the incoming signals and routes the inverted $BB_{I,pos}$ 430 $BB_{I,neg}$ 431 to the second mixer and the inverted $BB_{Q,pos}$ 432 and $BB_{Q,neg}$ 433 to the first mixer. Returning to FIG. 3, the baseband signals 305, 306 arriving at the first mixer 309 are described by Equations 21, 22, 23, and 24.

State 1: $BB_{I,pos} - BB_{I,neg}$ Equation 21

State 2: $(-1)*BB_{I,pos} - (-1)*BB_{I,neg}$ Equation 22

State 3: $BB_{Q,pos} - BB_{Q,neg}$ Equation 23

State 4: $(-1)*BB_{Q,pos} - (-1)*BB_{Q,neg}$ Equation 24

To facilitate the description of this embodiment, Equations 21, 22, 23 and 24 can be represented by the notations $+BB_I$, $-BB_I$, $+BB_Q$, and $-BB_Q$ respectively. $+BB_I$ represents the differential in-phase baseband signal with positive polarity. $-BB_I$ represents the differential in-phase baseband signal with negative polarity. $+BB_Q$ represents the differential quadrature baseband signal with positive polarity. $-BB_Q$ represents the differential quadrature baseband signal with negative polarity.

Likewise, the baseband signals 307, 308 arriving at the second mixer 310 are described by Equations 25, 26, 27, and 28.

State 1: $BB_{Q,pos} - BB_{Q,neg}$ Equation 25

State 2: $(-1)*BB_{Q,pos} - (-1)*BB_{Q,neg}$ Equation 26

State 3: $BB_{I,pos} - BB_{I,neg}$ Equation 27

State 4: $(-1)*BB_{I,pos} - (-1)*BB_{I,neg}$ Equation 28

As in the case with Equations 21-24, the Equations 25, 26, 27 and 28 can be represented by the notations $+BB_Q$, $-BB_Q$, $+BB_I$, and $-BB_I$ respectively.

Returning to FIG. 3, the local oscillator 320 waveform is transformed by a polyphase circuit 321 into four waveforms 322, 323, 324, and 325 each at the same frequency as the LO but with a phase shift referenced to the local oscillator phase. To continue the terminology established in the example associated with FIG. 2, these four
5 polyphase local oscillator signals 322, 323, 324, 325 will be denoted LO^0 , LO^{90} , LO^{180} , LO^{270} respectively.

The LO phase interleaver circuit 326 periodically switches configuration so that the LO^0 and LO^{180} periodically are routed to the first mixer 309 and are periodically
10 routed to the second mixer 310. Likewise, the LO phase interleaver 326 periodically routes LO^{90} and LO^{270} to the second mixer 310 and then to the first mixer 309. By switching the polyphase local oscillator signals to different mixers, it modulates the LO feed-through signal causing the LO feed-through peak energy to be reduced.

15 In the context of the present description, “interleaving” may refer to the plain and ordinary meaning thereof, as well as any sort of switching, exchanging, toggling, swapping, interchanging, etc.

Four LOPI combinations are illustrated in FIG. 5a, 5b, 5c and 5d. In state 1, as
20 illustrated in FIG. 5a, LO^0 500 and LO^{180} 501 are routed to the first mixer and LO^{90} 502 and LO^{270} 503 are routed to the second mixer. In the second state, as illustrated in FIG. 5b, the LO^0 510 and LO^{180} 511 are routed to the first mixer; however, they have been interchanged compared to the routing in state 1 represented in FIG. 5a. The effect of this interchange is to reverse the polarity of the signal. Returning to
25 FIG. 5b, LO^{90} 512 and LO^{270} 513 are routed to the second mixer; however, they too have been interchanged compared to state 1.

In state 3, as illustrated in FIG. 5c, LO^0 530 and LO^{180} 531 are routed to the second mixer and LO^{90} 532 and LO^{270} 533 are routed to the first mixer. In the fourth state,
30 as illustrated in FIG. 5d, the LO^0 540 and LO^{180} 541 are routed to the second mixer; however, they have been interchanged compared to the routing in state 3 represented

in FIG. 5c. The effect of this interchange is to reverse the polarity of the signal. Returning to FIG. 5d, LO⁹⁰ 542 and LO²⁷⁰ 543 are routed to the first mixer; however, they too have been interchanged compared to state 3.

- 5 Returning to FIG. 3, through the processes of local oscillator phase interleaving, each mixer input sees each polyphase LO signal LO⁰, LO⁹⁰, LO¹⁸⁰, LO²⁷⁰. Thus, if a phase or amplitude imbalance of one mixer distorts one LO component then it distorts all components. The LO signals 327, 328 arriving at the first mixer 309 are described by Equations 29, 30, 31 and 32. Likewise the LO signals 329, 330
10 arriving at the second mixer 310 are described by Equations 33, 34, 35 and 36.

	State 1:	$LO^0 - LO^{180}$	Equation 29
15	State 2:	$LO^{180} - LO^0$	Equation 30
	State 3:	$LO^{90} - LO^{270}$	Equation 31
	State 4:	$LO^{270} - LO^{90}$	Equation 32
20	State 1:	$LO^{90} - LO^{270}$	Equation 33
	State 2:	$LO^{270} - LO^{90}$	Equation 34
25	State 3:	$LO^0 - LO^{180}$	Equation 35
	State 4:	$LO^{180} - LO^0$	Equation 36

To facilitate the present description, Equations 29, 30, 31 and 32 can be represented
30 by the notations +LO_I, -LO_I, +LO_Q, and -LO_Q respectively. +LO_I represents the differential in-phase local oscillator signal with positive polarity. -LO_I represents the differential in-phase local oscillator signal with negative polarity. +LO_Q represents the differential local-oscillator signal with positive polarity. -LO_Q represents the differential quadrature local-oscillator signal with negative polarity. As in the case
35 with Equations 29-32, the Equations 33,34,35 and 36 can be represented by the notations +LO_Q, -LO_Q, +LO_I, and -LO_I respectively.

The LO feed-through at the output of the first mixer 309 and the second mixer 310 is dependent on the LO signal applied to the mixer and the individual characteristics of the mixer itself. Therefore, the LO feed-through at the output of first mixer 309 can be defined by Equations 37, 38, 39, and 40 and the LO feed-through at the output of the second mixer 310 can be define by Equations 41, 42, 43, and 44. The LO feed-through is defined by three subscripts and a precedent sign in these equations. As it is a function of the mixer, the first subscript indicates which mixer the feed-through is associated with. The switch matrix determines the LO feed-through relative polarity represented by a +/- precedent sign and its second subscript represents the in-phase or quadrature LO component. The third subscript, F, distinguishes it from the LO signal.

15	State 1:	$+ LO_{1,I,F}$	Equation 37
	State 2:	$- LO_{1,I,F}$	Equation 38
	State 3:	$+ LO_{1,Q,F}$	Equation 39
20	State 4:	$- LO_{1,Q,F}$	Equation 40
	State 1:	$+ LO_{2,Q,F}$	Equation 41
	State 2:	$- LO_{2,Q,F}$	Equation 42
25	State 3:	$+ LO_{2,I,F}$	Equation 43
	State 4:	$- LO_{2,I,F}$	Equation 44

30 A complex multiplicative term, $A1e^{jP1}$, represents a random amplitude variation ("A1") and a random phase variation ("P1") introduced by the first mixer 309, the signal path 305, 306 and LO path 327, 328 connected to the mixer. Likewise, $A2e^{jP2}$ represents a random amplitude and phase variation introduced by second mixer 310 and the signal 307,308 and LO paths 329,330 connected to it. Combining 315 the differential mixer outputs 311, 312, 313, 314 forms the RF output signal 316. The

RF output corresponding to the four interleaving states is described by Equations 45, 46, 47 and 48.

$$\begin{aligned} \text{State 1:} \quad & (+BB_I) \times (+LO_I) \times A1e^{jP1} + LO_{1,I,F} + \\ & (+BB_Q) \times (+LO_Q) \times A2e^{jP2} + LO_{2,Q,F} \\ & \text{Equation 45} \end{aligned}$$

$$\begin{aligned} \text{State 2:} \quad & (-BB_I) \times (-LO_I) \times A1e^{jP1} - LO_{1,I,F} + \\ & (-BB_Q) \times (-LO_Q) \times A2e^{jP2} - LO_{2,Q,F} \\ & \text{Equation 46} \end{aligned}$$

$$\begin{aligned} \text{State 3:} \quad & (+BB_Q) \times (+LO_Q) \times A1e^{jP1} + LO_{1,Q,F} + \\ & (+BB_I) \times (+LO_I) \times A2e^{jP2} + LO_{2,I,F} \\ & \text{Equation 47} \end{aligned}$$

$$\begin{aligned} \text{State 4:} \quad & (-BB_Q) \times (-LO_Q) \times A1e^{jP1} - LO_{1,Q,F} + \\ & (-BB_I) \times (-LO_I) \times A2e^{jP2} - LO_{2,I,F} \\ & \text{Equation 48} \end{aligned}$$

Equations 45, 46, 47, and 48 can be reduced to Equations 49, 50, 51, and 52 by combining signs.

$$\begin{aligned} \text{State 1:} \quad & BB_I \times LO_I \times A1e^{jP1} + LO_{1,I,F} + \\ & BB_Q \times LO_Q \times A2e^{jP2} + LO_{2,Q,F} \\ & \text{Equation 49} \end{aligned}$$

$$\begin{aligned} \text{State 2:} \quad & BB_I \times LO_I \times A1e^{jP1} - LO_{1,I,F} + \\ & BB_Q \times LO_Q \times A2e^{jP2} - LO_{2,Q,F} \\ & \text{Equation 50} \end{aligned}$$

$$\begin{aligned} \text{State 3:} \quad & BB_Q \times LO_Q \times A1e^{jP1} + LO_{1,Q,F} + \\ & BB_I \times LO_I \times A2e^{jP2} + LO_{2,I,F} \\ & \text{Equation 51} \end{aligned}$$

$$\begin{aligned} \text{State 4:} \quad & BB_Q \times LO_Q \times A1e^{jP1} - LO_{1,Q,F} + \\ & BB_I \times LO_I \times A2e^{jP2} - LO_{2,I,F} \\ & \text{Equation 52} \end{aligned}$$

In Equations 49 through 52, it can be seen that the RF signal LO feed-through components, $LO_{1,I,F}$, $LO_{1,Q,F}$, $LO_{2,I,F}$, and $LO_{2,Q,F}$, oscillate between positive and negative values. This results in the LO feed-through energy being spectrally spread away from the desired signal spectrum.

5

Since the LO feed-through term is being modulated at a frequency of the interleaving clock **340**, the LO feed-through is being spread with over a bandwidth equivalent to the frequency of the interleaving clock. As the interleaving clock frequency increases, the in-band distortion caused by the LO feed-through is reduced.

10

Furthermore, by using a delta signal modulator **341** the switching behavior of the BBI and LOPI can be modified as to shape the spectral characteristics of the LO feed-through.

15

In Equations 49 through 52, it can be seen that the RF signal quadrature imbalance components $A_1e^{jP_1}$ and $A_2e^{jP_2}$ are each multiplied to both the in-band and quadrature baseband signal components. The RF in-phase component $BB_I * LO_I$ has is modified by two values: $A_1e^{jP_1}$ for states 1 and 2 and $A_2e^{jP_2}$ for states 3 and 4. The quadrature baseband signal follows the opposite pattern for amplitude and phase imbalance. When the in-phase and quadrature signal components are modified by the amplitude and phase distortions at a much higher frequency than their own modulation bandwidths, the two distortion products are averaged together in effect. This is shown in Equation 53.

20

25

$$RF = (BB_I * LO_I) * ((A_1e^{jP_1} + A_2e^{jP_2})/2) + (BB_Q * LO_Q) * ((A_1e^{jP_1} + A_2e^{jP_2})/2)$$

Equation 53

30

So while the amplitude and phase distortion are still present in the RF signal, each signal component is distorted in the same fashion. Furthermore, the rapid switching of amplitude and phase distortion causes this distortion to be spread over a wide frequency and thus lowering its effects on in-band signal components.

The present embodiment may thus provide a solution for important drawbacks of direct conversion transmitters: LO feed-through and quadrature imbalance.

FIG. 6 is an illustration of a multi-mode wireless communication system in which one embodiment may be used. It should be understood that the components shown in FIG. 6 are merely representative of one mode of wireless communication system and that other communication systems may use different components in order to achieve similar, or even different results. For example, a wired transceiver communication system may also be employed. The claims, therefore, are not intended to be limited to the system shown in FIG. 6. For example, the present technology may be implemented in a single-mode system.

In the wireless communication system of FIG. 6, multi-mode, wireless communication devices, otherwise referred to herein simply as wireless communication devices, are shown as wireless communication devices **100a**, **100b**, and **100n**, one or more wireless communication devices being assigned to each user in the system. The designations a, b, and n on the wireless communication device identifiers correspond respectively to a first user, a second user, and an nth user, representing "n" number of users in the communication system. Although only three wireless communication devices **100** are shown in FIG. 6, it should be understood that a wireless communication system typically comprises many thousands of users.

Referring again to FIG. 6, control station **120** typically includes interface and processing circuitry for providing system control to base stations **110a** through **110n**, representing one through "n" base stations comprising the wireless communication system. Base stations are provided for transmitting and receiving communication signals to and from wireless communication devices. Each base station **110** provides a coverage area ranging up to several miles in radius from the base station location. As wireless communication devices travel within the coverage area of each base station, communication signals to be transferred to and from the wireless communication device are routed generally through the particular base station to

which the wireless communication device is most closely located.

Control station **120** provides circuitry for routing communications between wireless communication devices operating in various base station coverage areas, as well as
5 between remote stations and land-line telephone users through a Public Switch Telephone Network, shown in FIG. 6 as the PSTN **130**. Control station **120** may, alternatively, or in addition to, be connected to computer network **160** to provide communications between wireless communication devices in the communication system and various known computing devices connected to computer network **160**,
10 such as personal computers, mainframe computers, digital cameras, email systems, remotely controlled devices, and so on.

Control station **120** typically comprises a telecommunications switch (not shown) and a Base Station Controller (BSC) (also not shown). The telecommunication
15 switch provides a switching interface to PSTN **130** while the BSC provides the necessary hardware and software for communications to take place between base stations. Control station **120** provides other functions in the communication system as well, such as billing services and data services.

20 Control station **120** may be coupled to the base stations by various means such as dedicated telephone lines, optical fiber links, or microwave communication links. When a call is initiated by a wireless communication device, a paging message is transmitted to one or more base stations proximate to the wireless communication device initiating the call, generally over a paging channel. The paging message is
25 routed to control station **120**, where it is processed and routed either to PSTN **130** or to one or more base stations proximate to a wireless communication device for which the call is intended. When a call is initiated from PSTN **130**, a paging message is received by control station **120** where it is then converted into a format suitable for the particular wireless communication system.

30

In the exemplary embodiment, the wireless communication device **100** is able to communicate in at least two modes, or types, of communications, data communications and voice communications. Data communication mode is used when it is desirable to send or receive information generally suitable for digital computational devices, such as laptop computers. Data is generally transmitted in discrete segments called packets. Each data packet generally contains overhead information used for a variety of purposes. For example, many data packets contain a data field used to store an error detection code. The error detection code may be used to check a received data packet to ensure that it was received intact; that is, the data was not corrupted during the transmission process.

Voice communication mode is used when it is desirable to transmit acoustic information, including human speech, facsimile tones, music, or other audible forms of communication. In voice communication mode, audio information is transmitted using one or more well-known wireless communication modulation techniques, such as CDMA, TDMA, AMPS, and others.

During typical voice communications, an over the air channel is established between one or more base stations and a wireless telephone. The channel is maintained throughout the duration of the voice call, no matter how much or little voice activity is occurring between the wireless telephone and the base station. In many instances, voice data is digitized and formatted into packets prior to transmission. Voice packets differ from data packets in that no information as to a destination address is contained within the voice packets. That is, a connection is first established between two locations, then voice data is transmitted between the two locations. No address information need be contained within the voice packets as the source and destination of the voice packets are predetermined by the connection.

Data mode may further include a capability of transmitting voice in certain applications. In this scenario, voice is digitized. The digitized voice signals may be encrypted to provide for secure voice transmissions over the air. The digitized voice

signals are then formatted into data packets, which are then transmitted over the air using well-known data transmission protocols. As explained above, each data packet contains information as to the address, or destination, of where the data packet is to arrive.

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FIG. 7 illustrates the functional components of a wireless communication device, or wireless communication device, **100**, shown in block diagram format. It should be understood that the components shown in FIG. 7 are merely representative of one mode of wireless communication device and that other communication devices may use different components in order to achieve similar, or even different results. The claims, therefore, are not intended to be limited to the system shown in FIG. 7.

Wireless communication device **100** is capable of multi-mode communications, meaning that it can operate in several modes of communications, such as voice communications or data communications. It should be understood that voice communications comprise any audio information including speech, music, or audible tones used for call processing, modems, and facsimile machines. Data communications comprise synchronous or asynchronous data transmission. In addition to these modes, wireless communication device is also capable of other modes of communications as well.

A user of wireless communication device **100** initiates communications generally by using input device **200**. Input device **200** comprises a keypad in the exemplary embodiment, however, input device **200** could be any device which accepts user commands, such as a voice response device which converts voice commands into electrical signals suitable for processing by controller **202**. During voice communications, the user speaks into microphone **204**, which transforms acoustic energy into electrical energy and sends the electrical signals to controller **202** for processing.

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Microphone **204** may be substituted for input device **200** in an application where a second audio input device is undesirable. In many instances, a voice encoder/decoder, generally known as a Codec, is used between microphone **204** and controller **202**, or is incorporated within controller **202**, to convert the electrical
5 signals from microphone **204** into a format more suitable for transmission over a limited bandwidth air interface.

Speaker **206** is used to convert received electrical signals into acoustic signals. Speaker **206** may comprise a speaker suitable for low volume acoustic outputs,
10 typically for use in a traditional telephone application, or speaker **206** may comprise a loudspeaker, suitable for high volume acoustic outputs, typically for use in a dispatch applications. In another embodiment, speaker **206** may comprise a combination of the high volume and low volume acoustic speakers.

15 Wireless communication device **100** further comprises display **208** for allowing a user to view operational characteristics of the wireless communication device. Such displays are common in many of today's wireless devices including telephones and remote data terminals.

20 Data port **210** serves as an interface between controller **202** and external hardware devices. Data port **210** generally allows a variety of bi-directional data communications to take place between wireless communication device **100** and the external device. Such external devices include laptop computers, facsimile machines, and remote data terminals, among others.

25

When a user initiates voice or data communications, an identification code corresponding to a second communication device, generally a telephone number, is entered using input device **200**. In the exemplary embodiment, input device **200** comprises keys corresponding to digits 0 through 9, as well as additional function
30 keys, such as SEND, END, and so forth. Input device **200** may also comprise one or

more keys used to classify an outgoing communication as being a data communication or a voice communication.

For example, a user wishing to initiate a data communication might press a key
5 designated for data communications, then dial a telephone number corresponding to a data device that the user wishes to communicate with. In one embodiment, all calls from wireless communication device 100 are assumed to be voice calls, unless classified as some other mode of communication, as described by one of the methods above.

10
Controller 202 serves as the main computational unit of wireless communication device 100. Although controller 202 is shown as a single element in FIG. 7, it should be understood that controller 202 may comprise one or more individual components such as one or more Application Specific Integrated Circuits (ASICs) in combination
15 with memory devices, bus controllers, and other support devices well known to those skilled in the art.

To facilitate the transmission and receipt of wireless RF signals in the foregoing context, an RF transceiver 212 and an antenna 214 are coupled to controller 202 for
20 sending and receiving such signals. Similar to the controller 202, one or more ASICs in combination with memory devices, bus controllers, etc. may be used to provide the RF transceiver 212. Moreover, the aforementioned direct-conversion receiver may be incorporated into the RF transceiver 212 and/or controller 202 in any desired capacity for providing an improved system.

25
Working in conjunction with the controller 202 is memory 216. The memory 216 is a device used to store information represented in digital format. Examples of memory 216 include random access memory (RAM), electrically erasable programmable read-only memory (EEPROM), non-volatile memory, and other
30 known storage devices.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance
5 with the following claims and their equivalents.